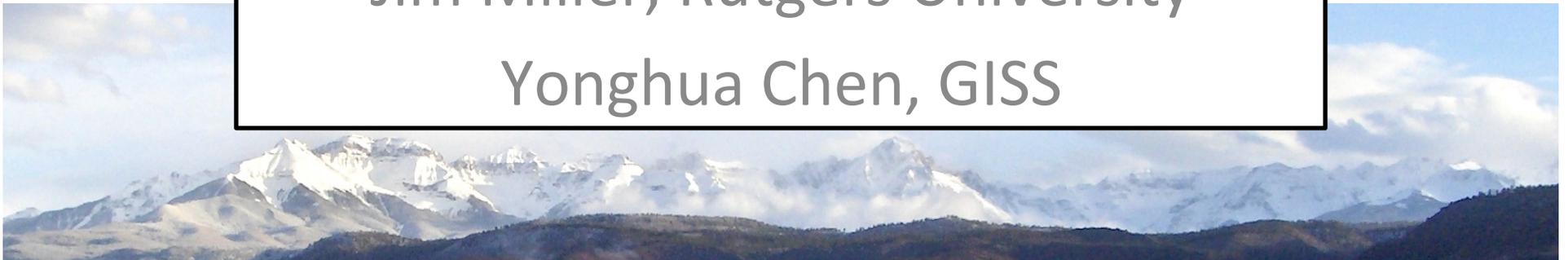


Climate change in high elevation regions: a short overview and some preliminary data analysis

Catherine Naud

Jim Miller, Rutgers University

Yonghua Chen, GISS



Layout

- Temperature trends at high elevations
- Other trends
- Cloud sensitivity?
- Snow-ice albedo?
- Water vapor?
- Model studies
- The satellite view: strengths and weaknesses



Quick facts



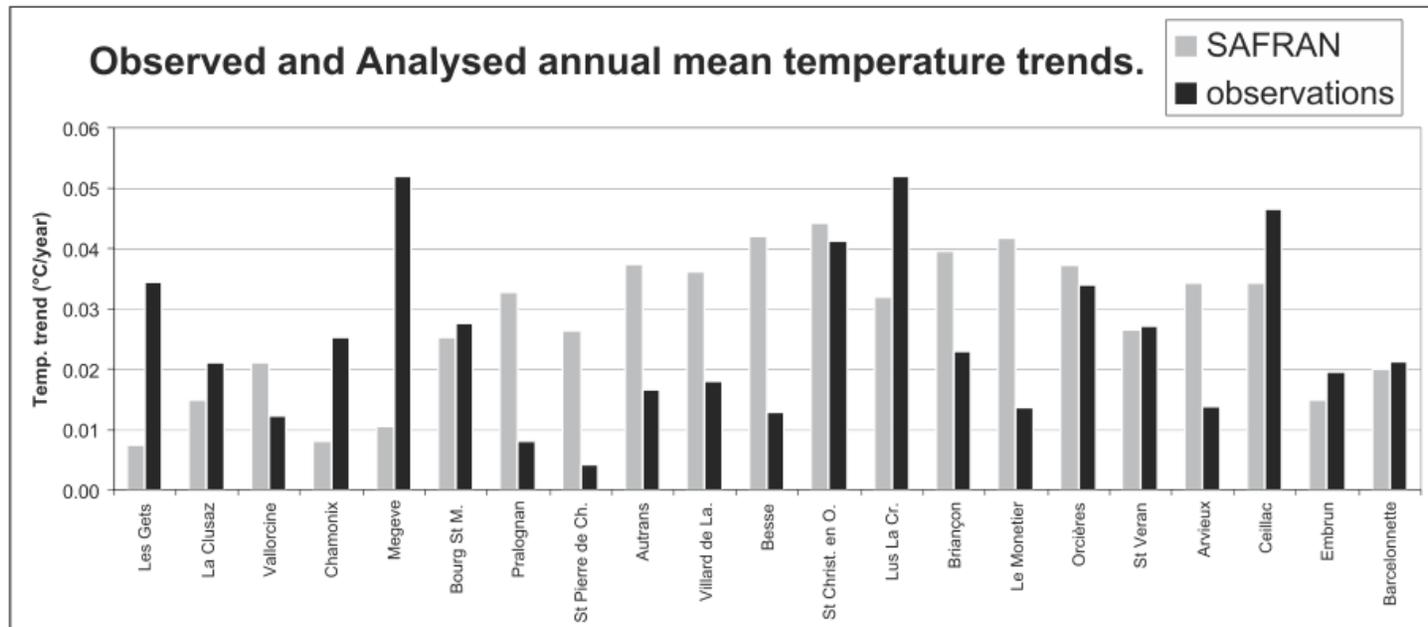
- Tropics: Kilimanjaro in Africa has little ice left
- Midlatitudes: ice melt affects water supply of large populations:
 - Tibetan Plateau (3rd pole):
China, India
 - Rockies: western US
 - Andes: western south America
 - Alps: central Europe



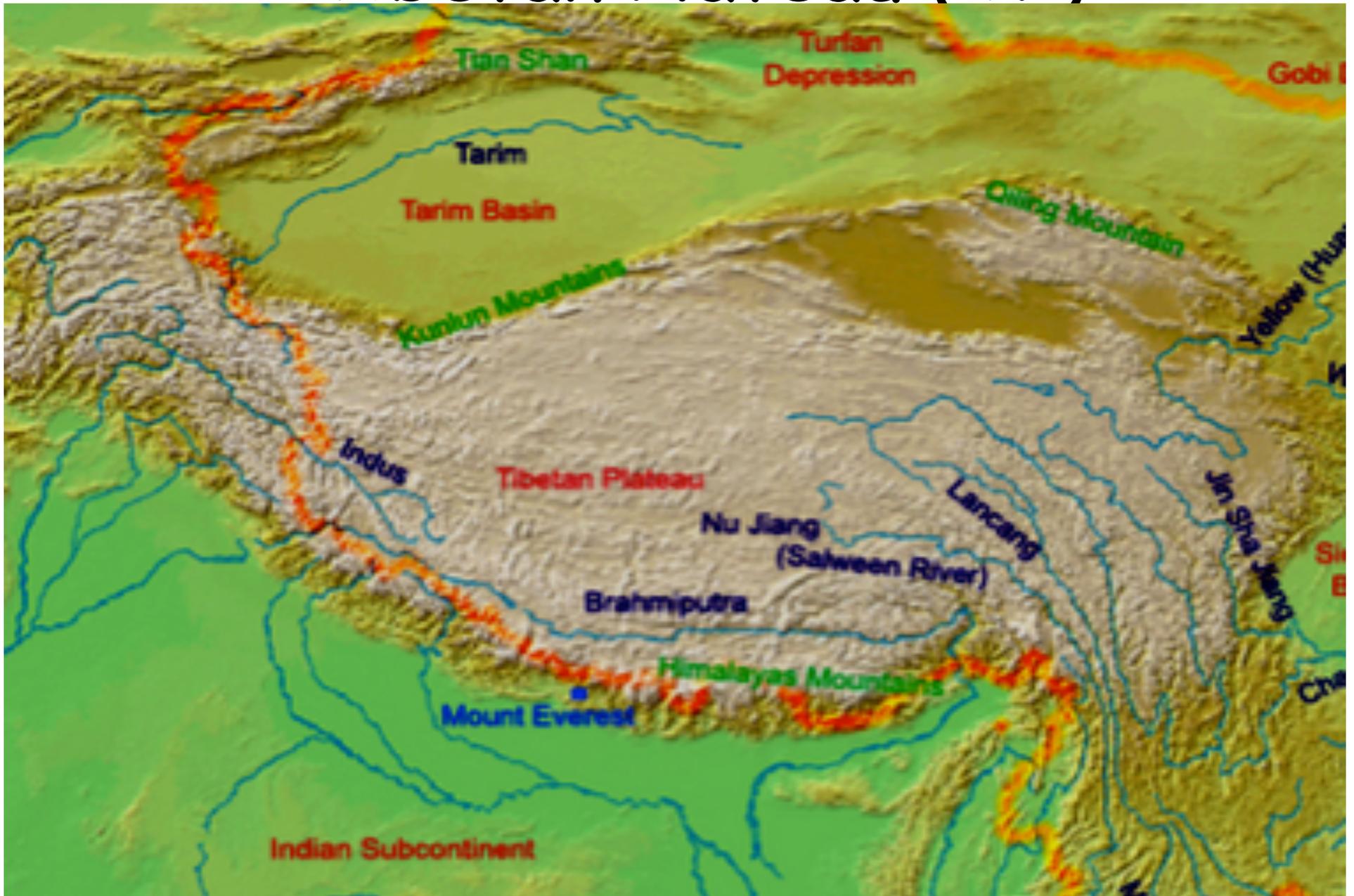
Temperature trend: Alps

- Warming trend: 1°C for 1958-2002 or 0.23°C/decade

Durand et al. JAMC 2009



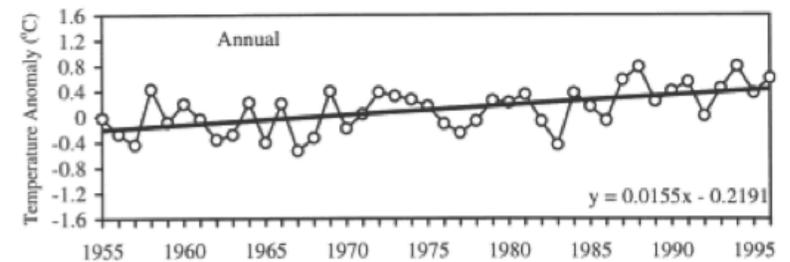
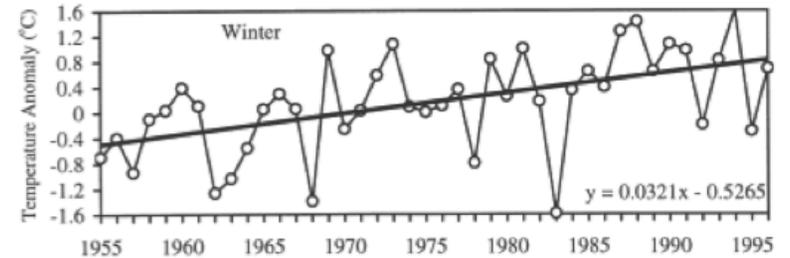
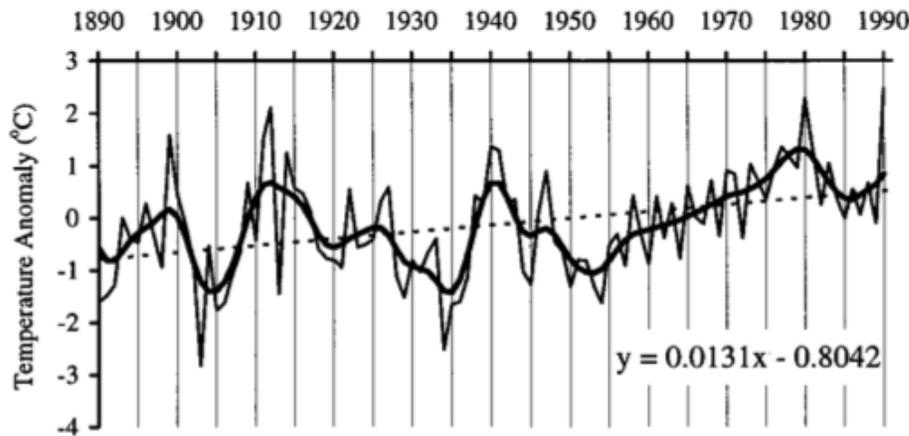
Tibetan Plateau (TP)



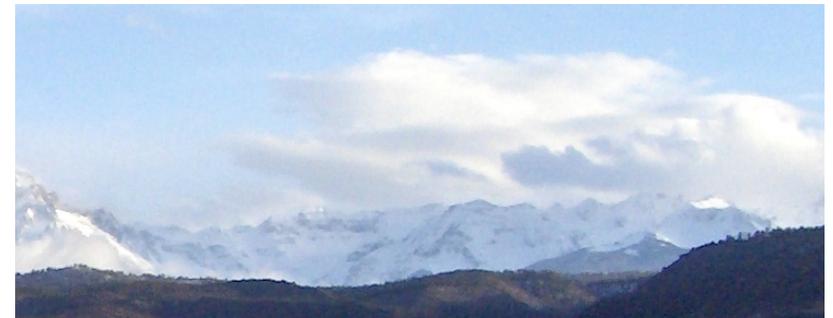
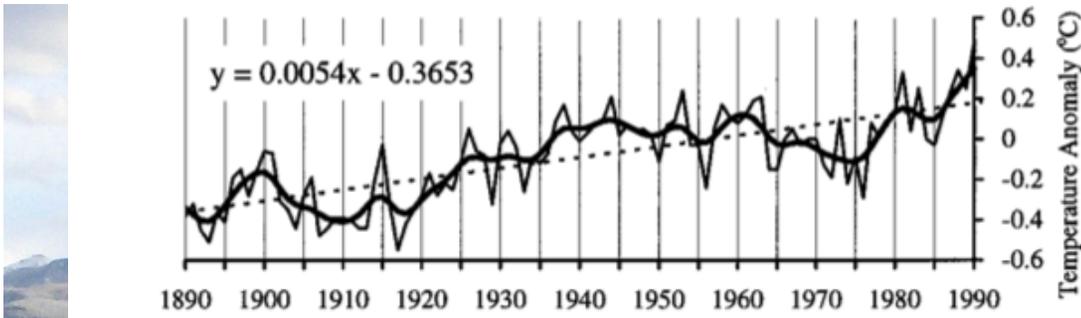
Temperature trend: Tibetan Plateau

Trend over the Plateau (1 station, $+0.13^{\circ}\text{C}/\text{decade}$)
 v.s.
 Trend for NH ($0.05^{\circ}\text{C}/\text{decade}$)

Liu and Chen, IJC 2000

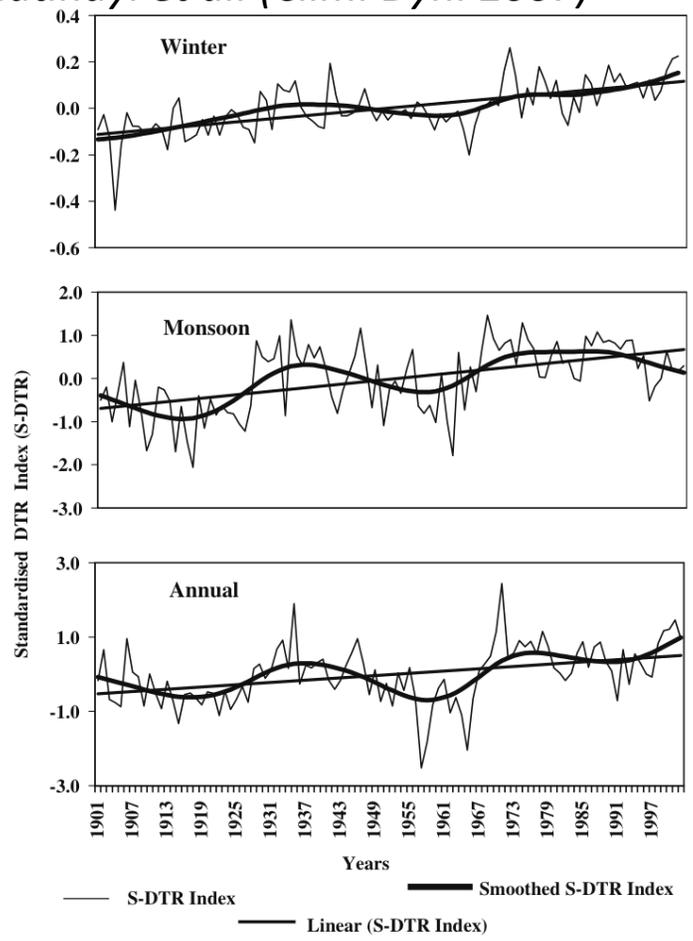


Winter trend ($+0.32^{\circ}\text{C}/\text{decade}$) vs
 annual trend ($+0.16^{\circ}\text{C}/\text{decade}$)
 (97 stations)

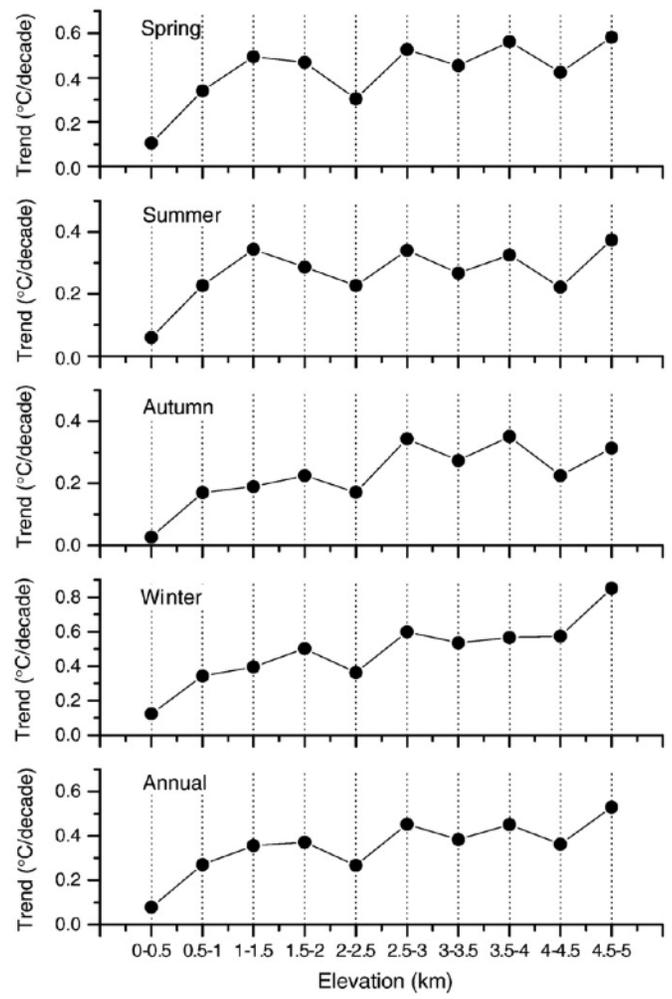


Temperature trend: Tibetan Plateau

Increase in diurnal temperature trend
(max T increase faster than min T)
Bhutinayi et al. (Clim. Dyn. 2007)

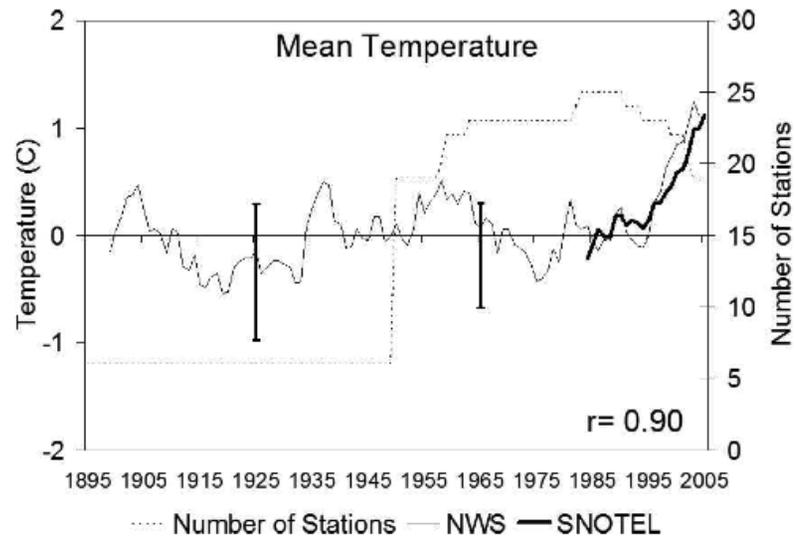


Trend vs elevation: increase with Z
Liu et al. (Glob. Planet. Change, 2009)



Temperature trend: Rockies

- Increase in temperature in southwestern Colorado: 1° for 1895-2005, or 0.09 °C/decade
 - Max T increase most in summer and min T in winter
- Rangwala and Miller (AAARes 2010)*



Temperature trend: Rockies

Koppen Tundra 1901–1930



Koppen Tundra 1987–2006

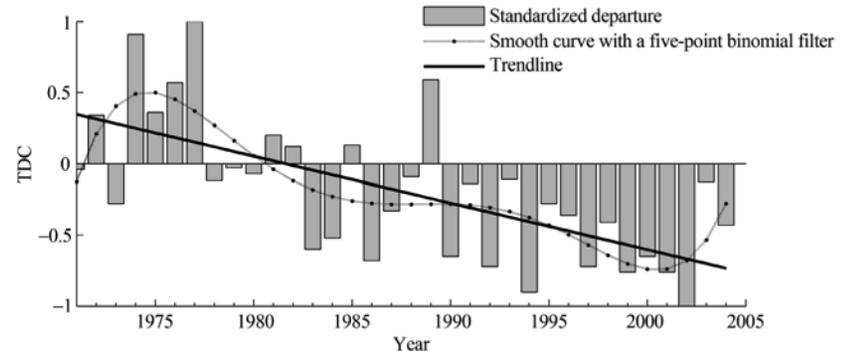


- Alpine tundra climate type receding in western US (region where maximum temperature during warm season between 0 and 10°C)
Diaz and Eischeid (GRL 2007) (left)



Other trends

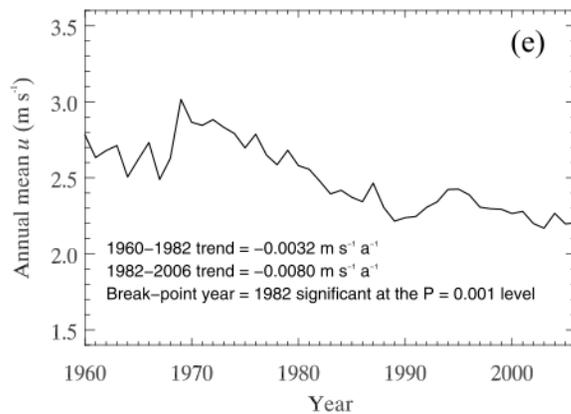
Clouds: decrease in cloud amount over Tibetan Plateau 1971-2002
Zhang et al J. Geogr. Sci. 2008



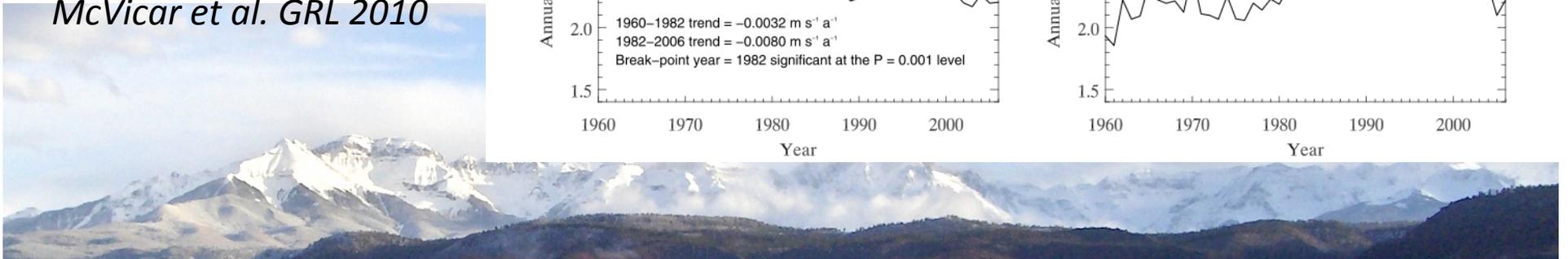
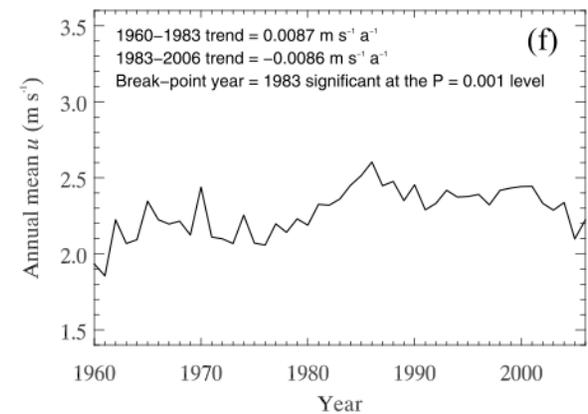
Near-surface winds: decrease in speed 1960-2006 in China and Alps. Greater rates with altitude.

McVicar et al. GRL 2010

Trend in China

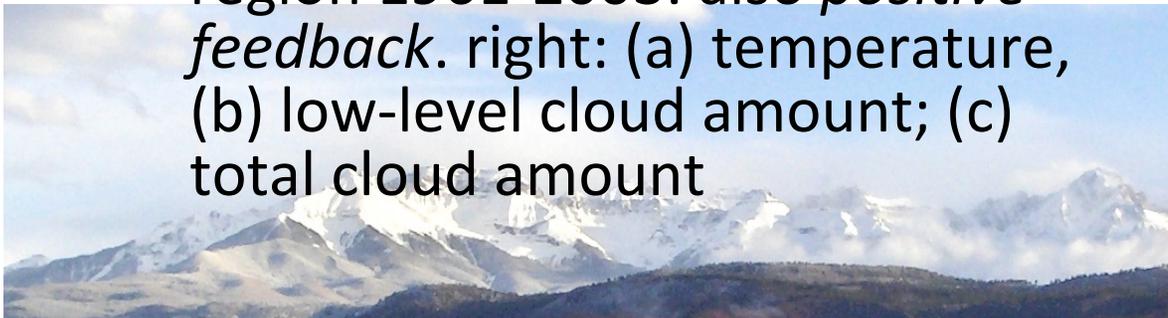
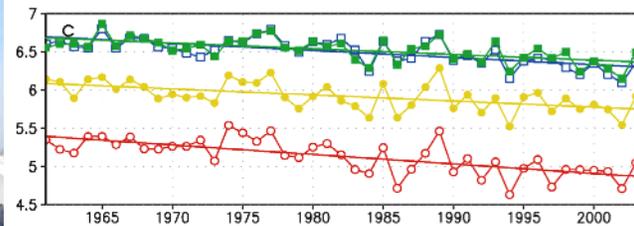
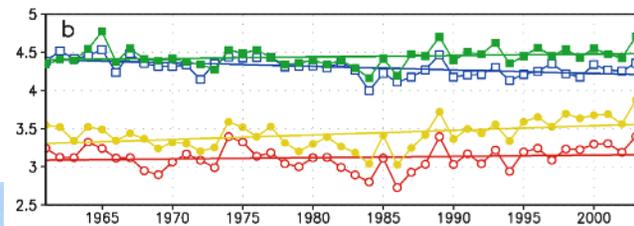
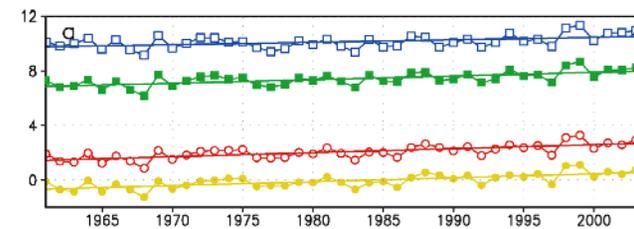
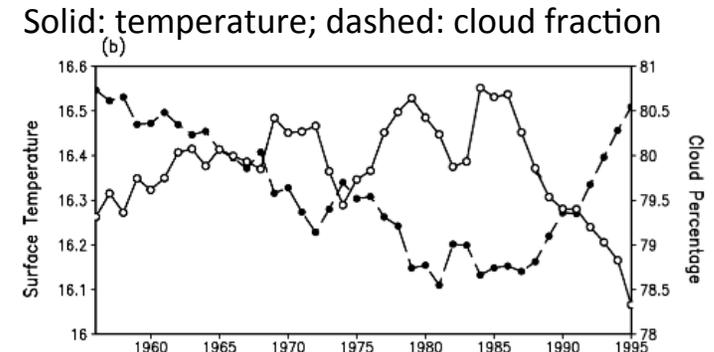


Trend in Switzerland



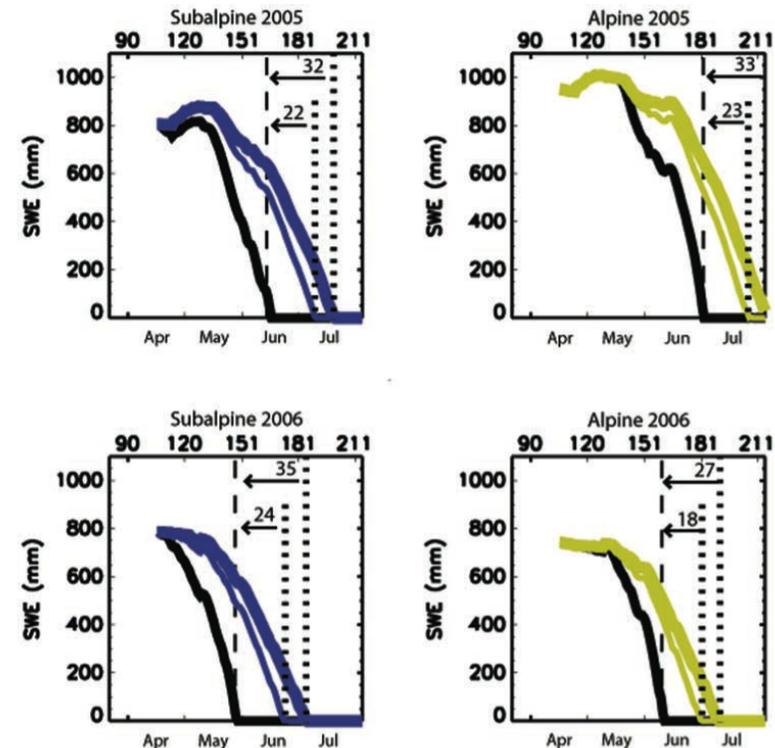
Sensitivities: clouds?

- Optically thick stratus deck over Tibetan plateau found to change with temperature: *positive feedback* => but eastern plateau shows cooling trend (Yu et al., JCLI 2004)
- Total cloud amount increase with temperature at night but decrease with temperature during the day (Duan and Wu GRL 2006)=> warming trend found over larger region 1961-2003. also *positive feedback*. right: (a) temperature, (b) low-level cloud amount; (c) total cloud amount



Sensitivities: Snow-ice albedo?

- Dust: desert soil disturbance=> dust deposition in Rockies=> darker snow=> earlier melt + more shortwave absorption (*Painter et al. GRL 2007*)
Increase in dust deposition in Mount Everest ice core since 1800s
- Soot: increase in soot deposition in Tibetan glaciers (*Xu et al PNAS 2009*) right: trends in BC and OC concentrations in ice core



Snow water-equivalent change in 2005 ("normal" dust) vs 2006 ("high" dust)

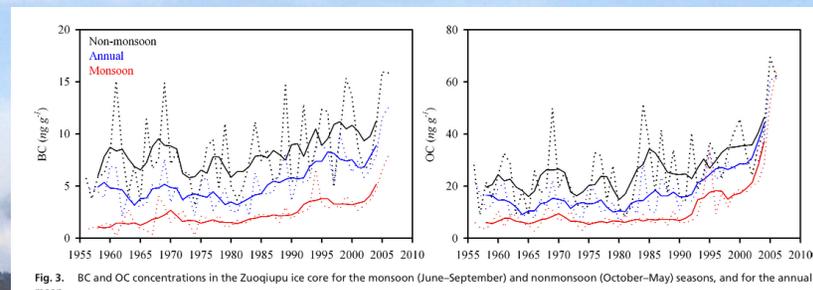
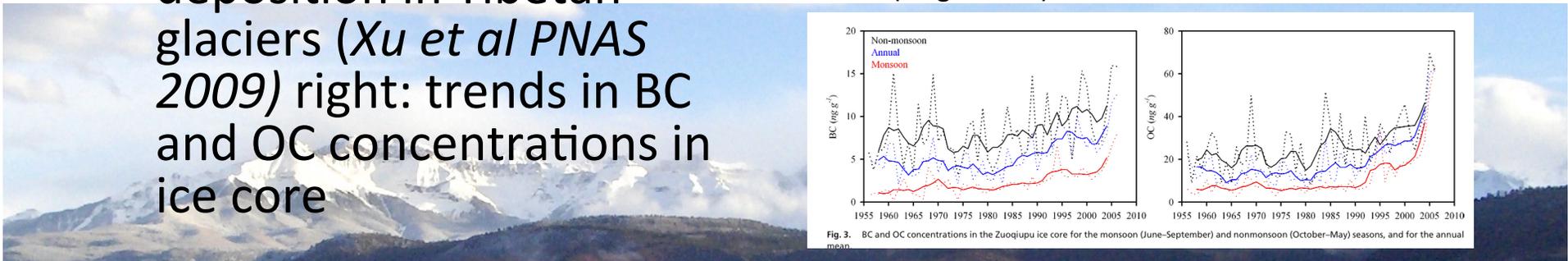


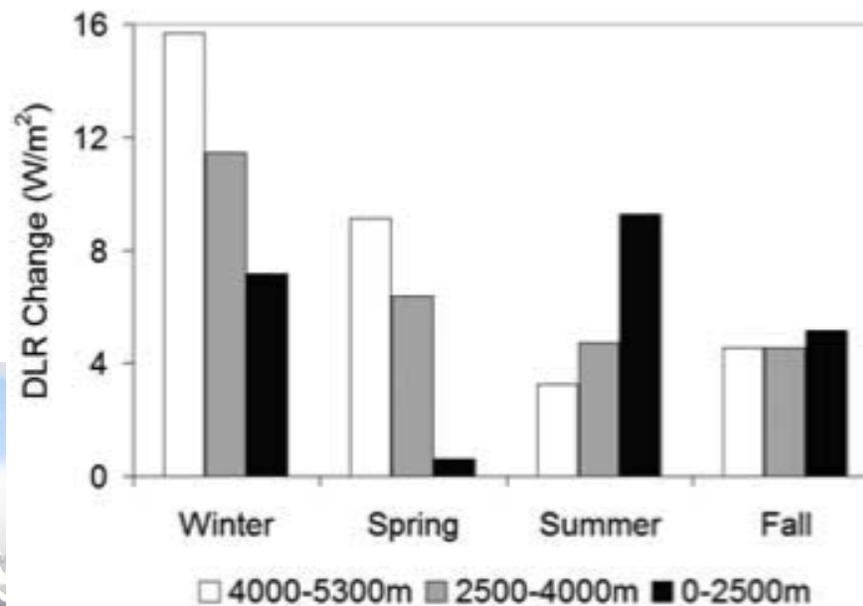
Fig. 3. BC and OC concentrations in the Zuoqiupu ice core for the monsoon (June–September) and nonmonsoon (October–May) seasons, and for the annual mean.



Sensitivities: water vapor

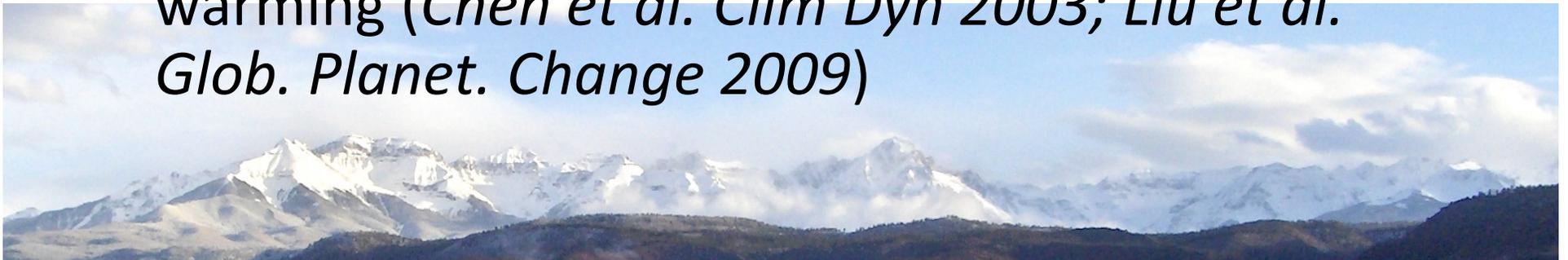
- Increase in specific humidity in Tibetan Plateau (1961-2000) => larger DLR => higher temperature esp. in winter and spring (*Rangwala et al GRL 2009*)

Estimated change in DLR based on observed change in specific humidity per season and elevation range



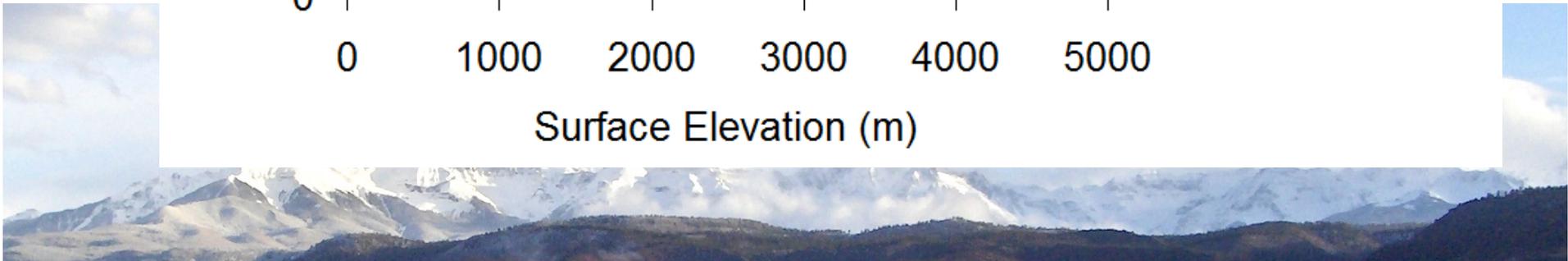
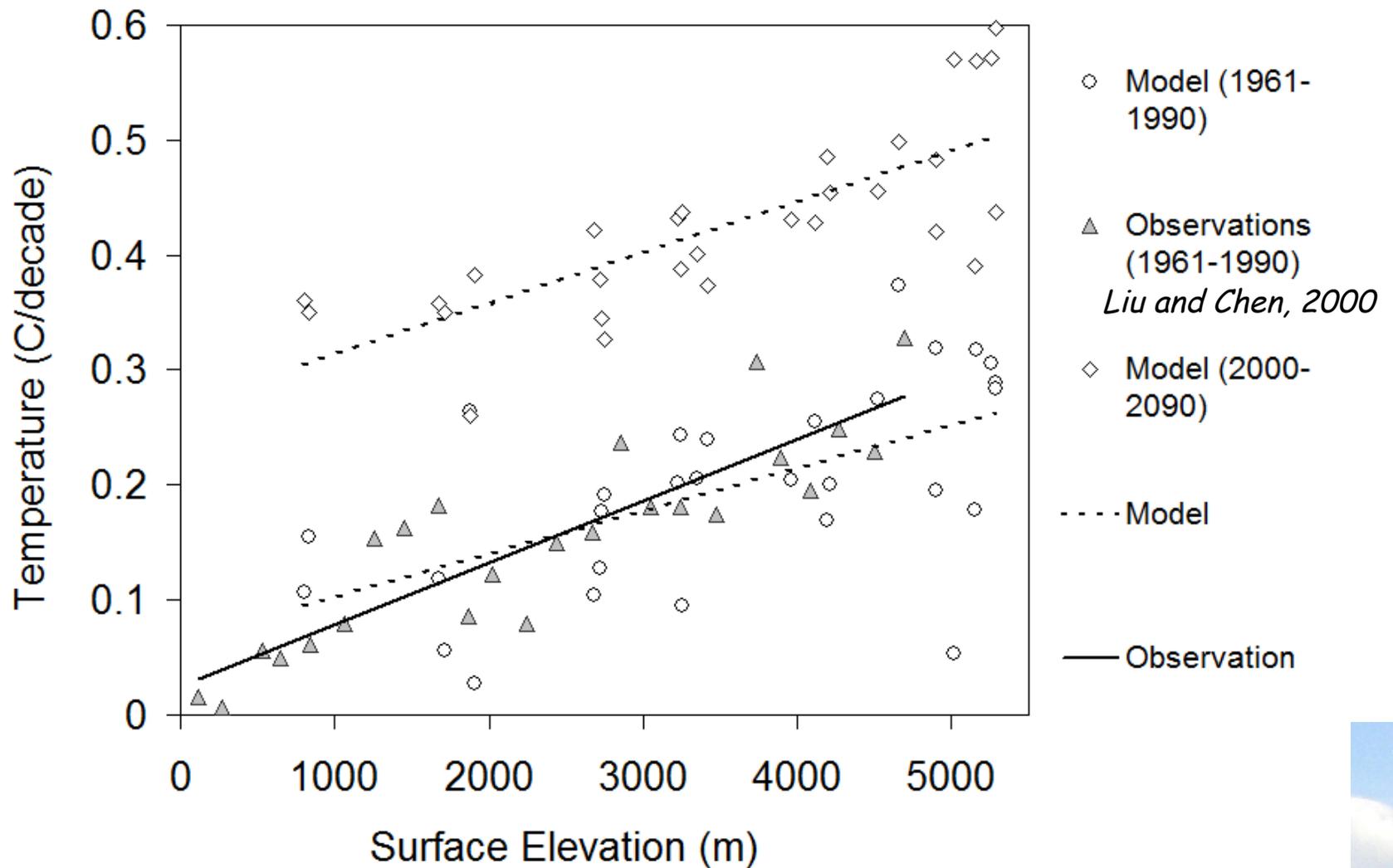
Model studies

- Soot: positive feedback in Rockies, esp. noticeable in late winter-spring, when melt season active. (*Qian et al. JGR 2009*)
- Humidity and change in snow cover both involved in simulated warming over Tibetan Plateau (*Rangwala et al. Clim Dyn 2010*)
- Cloud feedback to the east and snow cover to the west of Tibetan Plateau can explain simulated warming (*Chen et al. Clim Dyn 2003; Liu et al. Glob. Planet. Change 2009*)



Tibetan Plateau

Observed vs Modeled: Elevation Dependent Warming

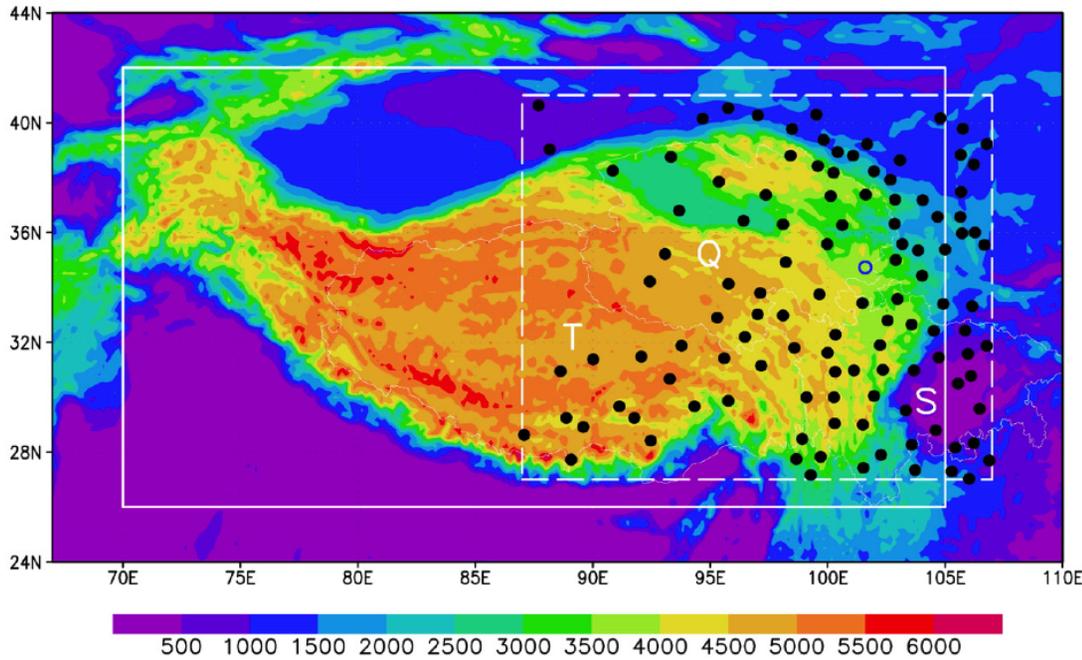


Sensitivities + issues

- Rockies: sensitivity to dust and soot => snow melt=> albedo => higher temperatures (observations and models)
- Tibet: sensitive to changes in clouds (esp. Eastern), in water vapor, and in snow cover (ep. West)
- => need more observations to decide importance of each factor



Issues with observations

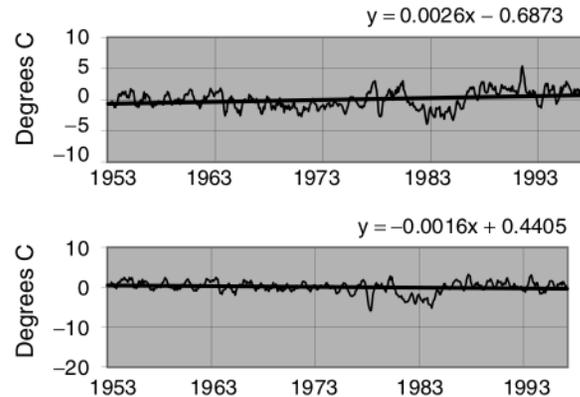


Limited network: Altitude distribution of Tibetan Plateau (Liu et al 2009) with some of the meteorological stations (note the lack of stations to the west).

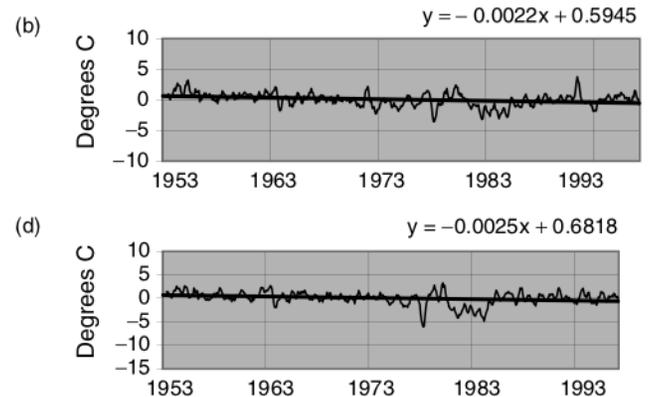
Different trends in different locations: *cooling* observed on the eastern side of the Rockies *Pepin and Losleben (IJC 2002)*

Impact of Topography?
Large scale?

3000m: max and min T trends



3700m: max and min T trends



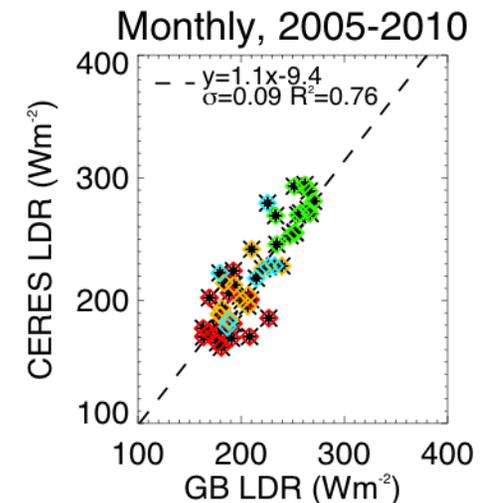
Satellite view: strengths and weaknesses

- Satellite have global view, and can observe remote areas on a regular time step
- Resolution may cause issues where altitudes highly variable
- Bright surfaces not great for remote sensing
- Short period available (30 years max), not great for trends
- Multiple variables observed simultaneously, so inter-relationships can be observed=> ideal to study feedback loops
- => How do existing products perform in tricky areas such at Tibet or Rockies?

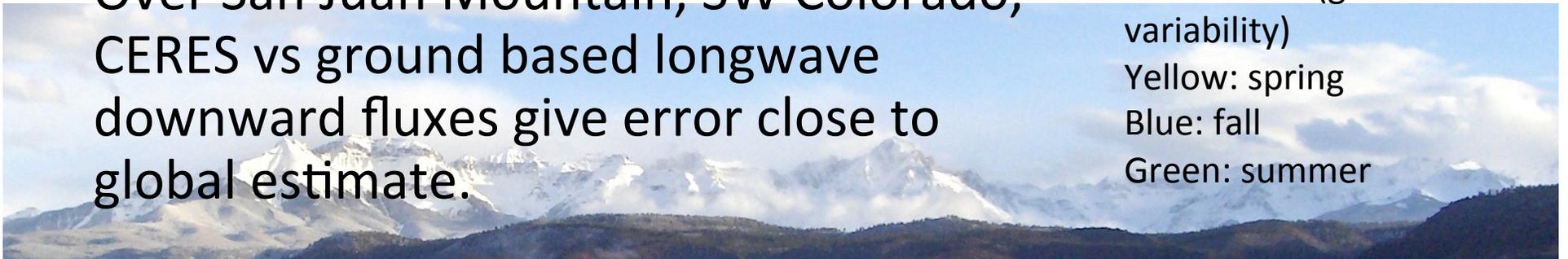


Radiation

- Yang et al tested retrievals over the Tibetan Plateau region of surface shortwave (JGR 2008, GRL 2009) and longwave fluxes (GRL 2009) from various missions and found large errors over highly varying terrain but less so over the Tibetan Plateau itself (close to global average). Issue is surface and atmosphere inputs.
- Over San Juan Mountain, SW Colorado, CERES vs ground based longwave downward fluxes give error close to global estimate.



Red: winter (greater variability)
Yellow: spring
Blue: fall
Green: summer

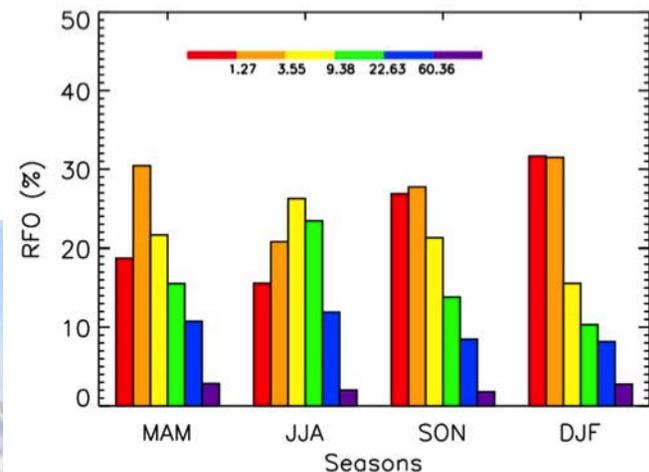
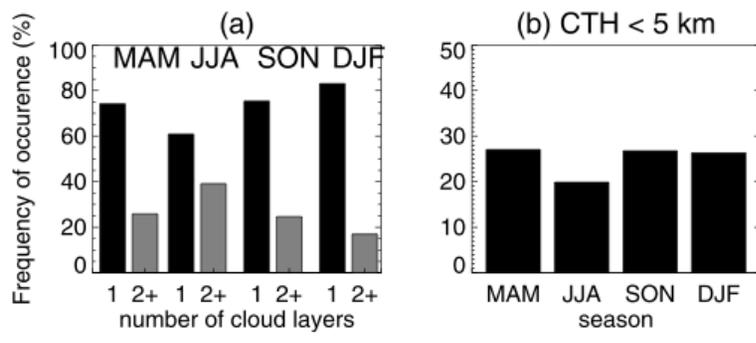


Clouds

- ISCCP vs CloudSat-CALIPSO cloud frequency of occurrence over Tibetan Plateau:
 - ISCCP misdetection of clouds within 5 km of surface or optically thin (problematic in winter)
 - ISCCP CTP overestimated when multiple layers: relatively rare in winter over Tibetan Plateau

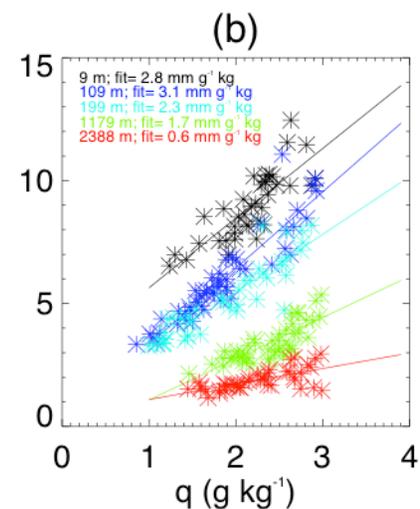
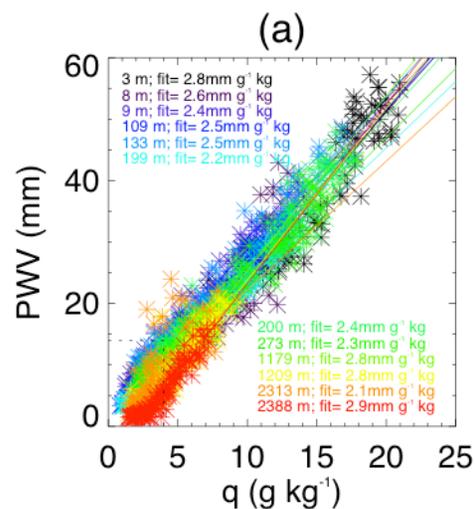
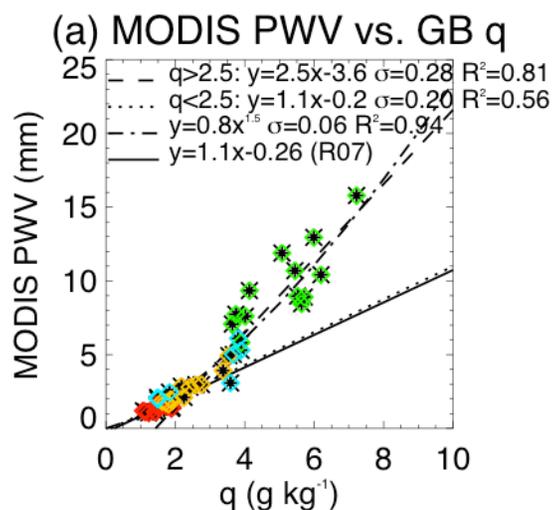
Errors in ISCCP cloud products consistent with lower altitude estimates

Naud and Chen JGR 2010



Water vapor

- MODIS PWV vs surface specific humidity: San Juan observations from Center for Snow and Avalanche Studies => MODIS PWV vs q similar relation as GPS vs q for Alps



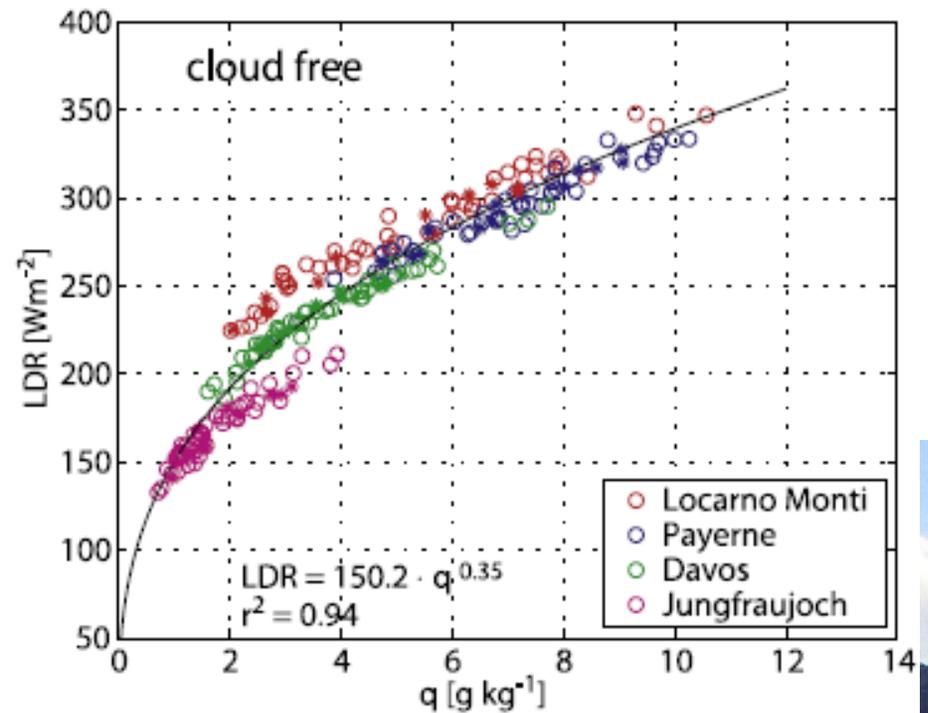
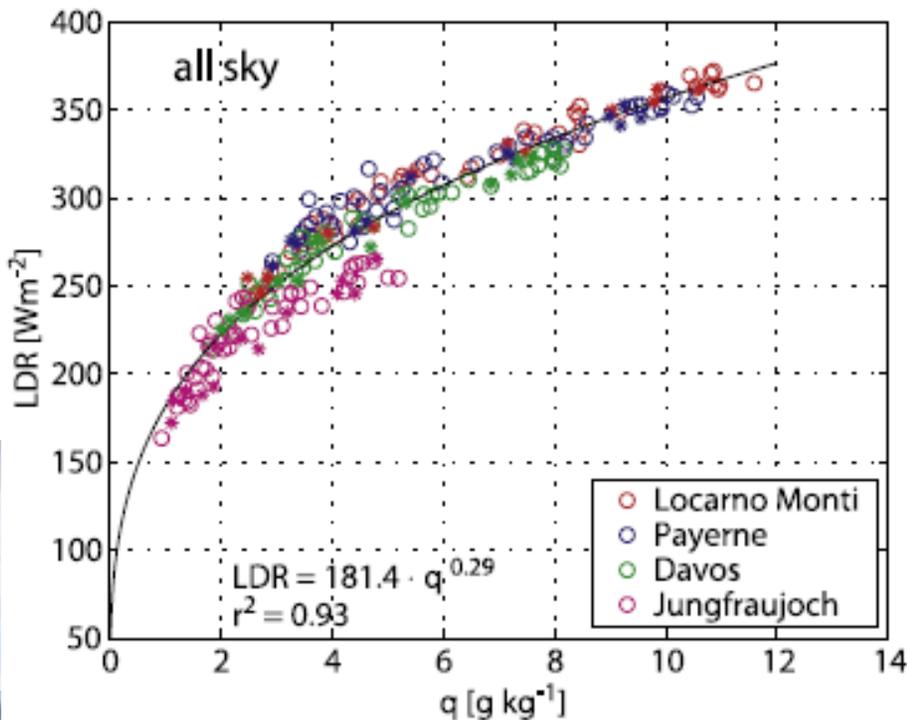
MODIS PWV vs GB q: agree for low values of q with GPS vs q in the Alps at similar elevation, but not for large q

MODIS vs Weather stations across the US: for $q > 4$ g kg⁻¹ linear relation between MODIS PWV and surface q (slope ~ 2.5 = Ruckstuhl et al 2007 for the Alps and GPS PWV)

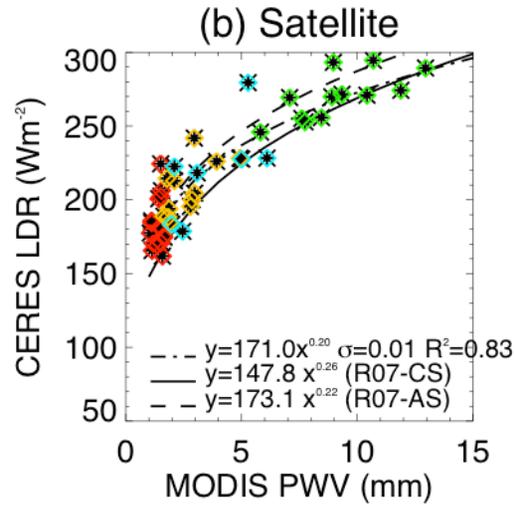
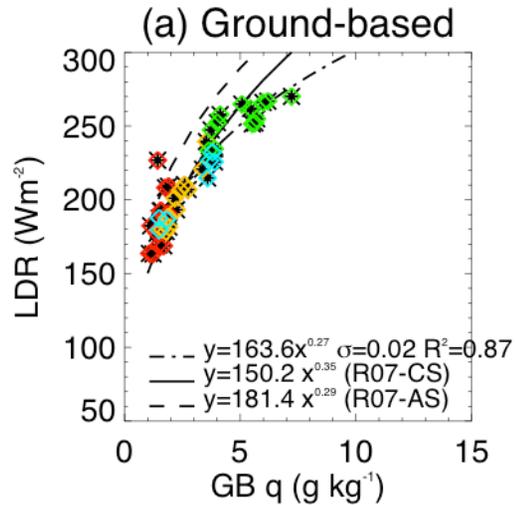
LDR vs humidity: Alps

- Ground based relationship for 4 stations from 388 to 3584 m; *Ruckstuhl et al. JGR 2007*

Monthly means in DLR and q from 2001-2004

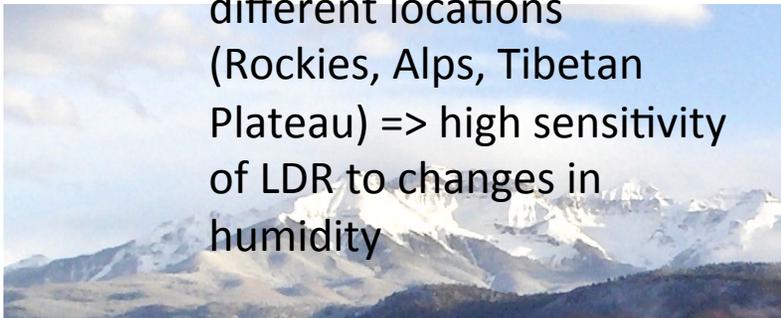
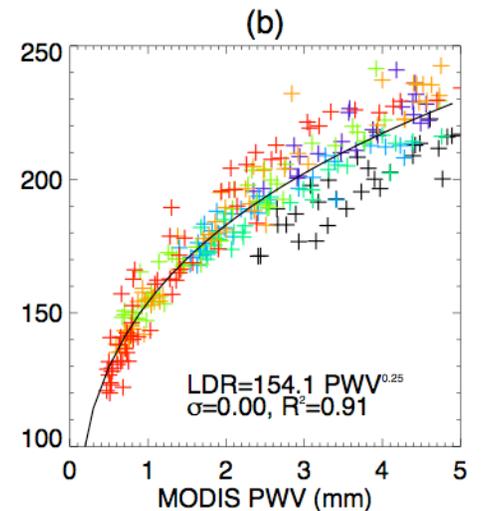
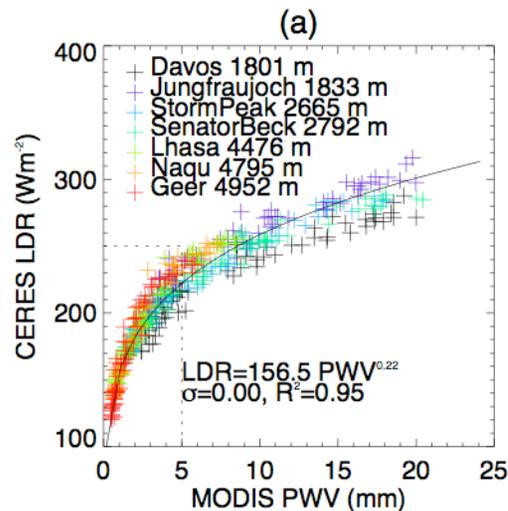


Satellite based relationship LDR vs humidity



CERES & MODIS vs Ground-based derived relationship at San Juan: agreement with similar study over the Alps

Relationship CERES LDR/
MODIS PWV preserved for
different locations
(Rockies, Alps, Tibetan
Plateau) => high sensitivity
of LDR to changes in
humidity



Conclusions

- Warming at high elevations at greater rate than other altitudes
- Which factors accelerate warming at high elevations?
- Satellite retrievals could be used to study feedback loops at high elevations, even if errors larger

